COMMERCIAL DEMONSTRATION OF THE NOXSO SO_2/NO_x REMOVAL FLUE GAS CLEANUP SYSTEM

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Front End Engineering/Environmental Evaluation Phase

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EXECUTIVE SUMMARY

The NOXSO process is a dry, post-combustion flue gas treatment technology which uses a regenerable sorbent to simultaneously adsorb sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from flue gas. In the process, the SO_2 is converted to a sulfur by-product (elemental sulfur, sulfuric acid, or liquid SO_2) and the NO_x is converted to nitrogen and oxygen.

The objective of the NOXSO Clean Coal Project is to design, construct, and operate a flue gas treatment system utilizing the NOXSO process at Alcoa Generating Corporation's (AGC) Warrick Power Plant. The NOXSO plant is being designed to remove 98% of the SO_2 and 75% of the NO_x from the flue gas from the 150-MW equivalent, unit 2 boiler. The by-product to be generated by the project is liquid SO_2. Sufficient construction cost and operating data will be obtained during the project to confirm the process economics and provide a basis to guarantee performance on a commercial scale.

The project is in the Front End Engineering/Environmental Evaluation Phase. Engineering activities are approximately 20% complete and activities to update the project estimate based on completed engineering and equipment bids have been initiated. The Environmental Information Volume (EIV) for compliance with the National Environmental Policy Act (NEPA) is being prepared and will be completed within the next month.

Activities required to obtain project funding are proceeding. Indiana state legislation which would enable NOXSO to sell revenue bonds issued and guaranteed by the state has been proposed. The legislation was unanimously approved by the Senate and is being reviewed in the House. No opposition is expected. Negotiations are proceeding to sell the sulfur by-product to Olin Corporation to generate revenue to partially repay these bonds. The remaining bond debt will be repaid by selling SO_2 allowances generated by the project.

Process study activities include laboratory fluid-bed adsorber studies, regenerator computer model development and studies, fluid-flow modelling in fluid-bed vessels, and evaluations of SO_2 production processes. The laboratory-scale, fluid-bed adsorber studies are being conducted to improve the accuracy of the removal efficiency predictions and study the impact of adding a third adsorber stage. The construction of the steel, multi-stage reactor is currently underway. The regenerator computer model was revised and is being used to study design options for improving the regenerator performance. Fluid-flow modelling has been conducted to study the effect of grid supports on the gas flow inside the fluid bed vessels. The site for the liquid SO_2 facility has been chosen. The plant will be constructed at Olin Corporation's, Charleston, TN site.

1 PROJECT DESCRIPTION

The objective of the NOXSO Demonstration Project (NDP), with cost-shared funding support from DOE, is to design, construct, and operate a commercial-scale flue gas cleanup system utilizing the NOXSO process. The NDP consists of the NOXSO plant and sulfur recovery unit, designed to remove SO_2 and NO_X from flue gas and produce elemental sulfur by-product, and the liquid SO_2 plant and air separation unit, designed to process the elemental sulfur into liquid SO_2. The NOXSO plant and sulfur recovery unit will be constructed at ALCOA Generating Corporation's (AGC) Warrick Power Plant near Evansville, Indiana, and will treat all of the flue gas from the 150-MW Unit 2 boiler. The elemental sulfur produced will be shipped to the Olin Charleston Plant in Charleston, Tennessee, for conversion into liquid SO_2.

The goals of the NDP include the reduction of the Warrick Power Plant Unit 2 SO_2 and NO_X emissions by 98% and 75%, respectively, and the waste minimization through the beneficial use of the sulfur by-product. In addition, construction costs and operating data from the project will be used to confirm the process economics and provide a basis to guarantee performance on a commercial scale. Ultimately, the successful demonstration of this process would assist utilities in attaining the emission limits specified by the 1990 Clean Air Act Amendments.

2 PROCESS DESCRIPTION

The NOXSO process is a dry, post-combustion flue gas treatment technology which will use a regenerable sorbent to simultaneously adsorb sulfur dioxide (SO_2) and nitrogen oxides (NO_x) from the flue gas from Unit 2 of AGC's Warrick Power Plant. In the process, the SO_2 will be converted to liquid SO_2 and the NO_x will be reduced to nitrogen and oxygen. The NOXSO plant is being designed to remove 98% of the SO_2 and 75% of the NO_x. Details of the NOXSO process are described with the aid of Figure 1-1. Flue gas from the power plant is drawn through two flue gas booster fans which force the air through two-stage fluid-bed adsorbers and a baghouse before passing to the power plant stack. For simplicity, only one adsorber train is shown in Figure 1-1. Water is sprayed directly into the adsorber fluid beds as required to lower the temperature to 250-275°F by evaporative cooling. The fluid-bed adsorber contains active NOXSO sorbent, a 1.6 mm average diameter stabilized γ-alumina bead impregnated with sodium. SO_2 and NO_X are adsorbed on the sorbent simultaneously by the following reactions:

$$Na_2O + SO_2\ (g) \rightleftarrows Na_2SO_3 \qquad (2\text{-}1)$$

$$Na_2SO_3 + 1/2\ O_2\ (g) \rightarrow Na_2SO_4 \qquad (2\text{-}2)$$

$$Na_2O + SO_2\ (g) + NO\ (g) + O_2\ (g) \rightleftarrows Na_2SO_4 + NO_2\ (g) \qquad (2\text{-}3)$$

$$Na_2O + 3\ NO_2\ (g) \rightleftarrows 2\ NaNO_3 + NO\ (g) \qquad (2\text{-}4)$$

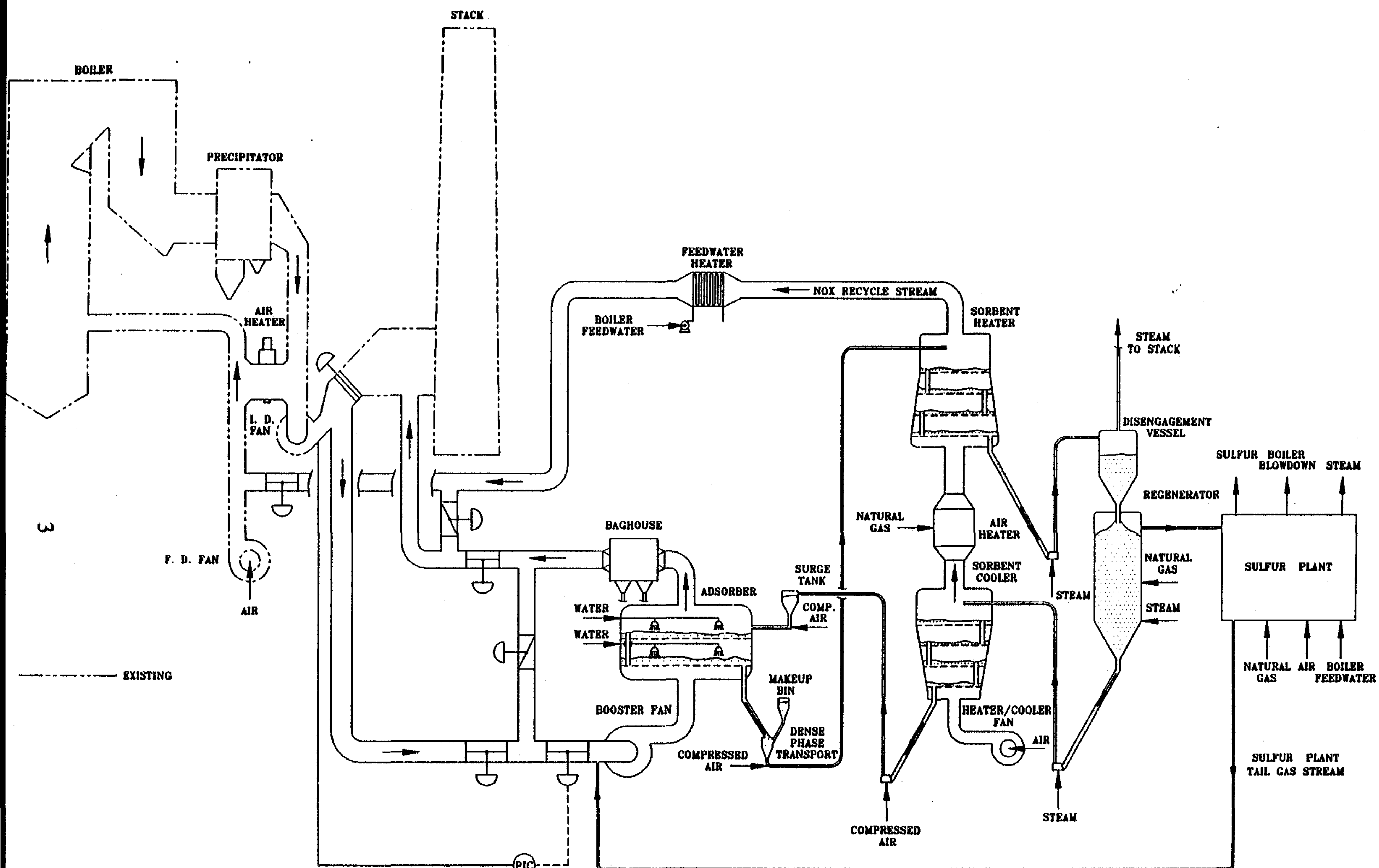


Figure 1-1. NOXSO Process Diagram
Alcoa Generating Company
Warrick Plant Unit 2

A baghouse separates sorbent which may be entrained in the flue gas and directs it to the fly ash sluicing system. Spent sorbent from the adsorbers flows into a dense-phase conveying system which lifts the sorbent to the top bed of the sorbent heater vessel. The sorbent flows through the four-stage fluidized bed sorbent heater in counterflow to the heating gas which heats the sorbent to the regeneration temperature of approximately 1150°F.

In heating the sorbent, the NO_x is driven off by the following reactions:

$$2\ NaNO_3 \rightarrow Na_2O + 2\ NO_2\ (g) + 1/2\ O_2\ (g) \qquad (2\text{-}5)$$

$$2\ NaNO_3 \rightarrow Na_2O + NO_2\ (g) + NO\ (g) + O_2\ (g) \qquad (2\text{-}6)$$

The evolved NO_x is then carried to the power plant boiler in the NO_x recycle stream. The NO_x recycle stream is cooled from approximately 360°F to 140°F in the feedwater heater. This heat-exchanger heats a slip stream of the power plant's feedwater, thereby reducing the amount of extraction steam taken from the low pressure turbine. The cooled NO_x recycle stream replaces a portion of the combustion air. The presence of NO_x in the combustion air suppresses the formation of NO_x in the boiler resulting in a net destruction of NO_x.

The heated sorbent is transported through an L-valve to the steam disengaging vessel. Transport steam is separated from the sorbent to reduce the volume of the off-gas stream. Sorbent gravity flows into the regenerator where it is contacted with natural gas. The sulfur on the sorbent combines with the methane and forms SO_2 and H_2S by the following series of chemical reactions.

$$4\ Na_2SO_4 + CH_4\ (g) + 4\ Al_2O_3 \rightarrow 8\ NaAlO_2 + 4\ SO_2\ (g) + CO_2\ (g) + 2\ H_2O\ (g) \qquad (2\text{-}7)$$

$$CH_4\ (g) + 4/3\ SO_2\ (g) \rightleftarrows CO_2\ (g) + 2/3\ H_2O\ (g) + 4/3\ H_2S\ (g) \qquad (2\text{-}8)$$

$$SO_2 + CH_4\ (g) \rightleftarrows COS\ (g) + H_2\ (g) + H_2O\ (g) \qquad (2\text{-}9)$$

$$H_2S\ (g) + Na2SO_4 + Al_2O_3 \rightarrow 2\ NaAlO_2 + SO_2\ (g) + H_2O\ (g) + 1/x\ S_x \qquad (2\text{-}10)$$

$$H_2\ (g) + Na_2SO_4 + Al_2O_3 \rightarrow 2\ NaALO_2 + SO_2\ (g) + H_2O\ (g) \qquad (2\text{-}11)$$

$$H_2\ (g) + 1/x\ S_x \rightarrow H_2S\ (g) \qquad (2\text{-}12)$$

Additional regeneration occurs in the steam treater section of the regenerator when the sorbent is contacted with steam, converting the remaining sulfur on the sorbent to H_2S. The regenerator off-gas stream is directed to a sulfur recovery plant where the H_2S and SO_2 are converted to elemental sulfur. Tail gas from the sulfur recovery plant will be oxidized and recycled back through the adsorbers to remove any residual sulfur compounds.

The elemental sulfur will be shipped to Olin Corporation where it will be oxidized to SO_2 using a stream of oxygen. The SO_2 vapor is then separated from other gaseous components, compressed, and liquified.

High temperature sorbent exiting the regenerator is conveyed with an L-valve to the four-stage fluidized-bed sorbent cooler. The sorbent flows counter to the ambient air which cools the sorbent. Regenerated sorbent exits the cooler at 320°F. The sorbent is then conveyed through an L-valve to the sorbent surge tank before being returned to the adsorber, completing the sorbent cycle.

Ambient air which is forced through the sorbent cooler by the heater-cooler fans exits the sorbent cooler at approximately 950°F. This preheated air then enters the air heater where it is heated to approximately 1340°F so it is capable of heating the sorbent exiting the sorbent heater to 1150°F.

3 PROJECT STATUS

The project is currently in the Front End Engineering/Environmental Evaluation Phase. The primary objectives of this phase include completion of front end engineering efforts, satisfying NEPA, reverification of the project budget, and obtaining commitments for project cost share.

Front end engineering activities are progressing with emphasis on process design and preparation of equipment specifications, preliminary civil and foundation designs and a preliminary general arrangement. Engineering is approximately 20% complete.

The Environmental Information Volume (EIV) is near completion. The Alcoa-Warrick portion of the EIV which includes the NOXSO plant is approximately 95% complete. The Olin-Charleston portion of the EIV was recently begun and is proceeding rapidly and will be completed during the next quarter.

Activities to reverify the project cost are ongoing in the form of preparation of equipment specifications and requests for quote (RFQ). The stage of engineering completion allows these activities to be initiated.

Most of NOXSO's cost share will be obtained through the sale of Indiana revenue bonds guaranteed by the state if recently proposed legislation is passed. Indications are the legislation will become law without opposition since it was unanimously approved in the state Senate and no opposition has been identified in the House.

NOXSO's ability to repay the bonds depends on generating revenue from the sale of the sulfur by-product. The agreement to sell the by-product to Olin Chemical Corporation is proceeding and is expected to be executed in April.

3.1 Project Management

In general, project management efforts focused on coordinating activities between NOXSO, Alcoa, MK, and Olin to satisfy design and procurement activities of the project. Additionally, significant effort was expended to assure the necessary events occur to enable NOXSO to raise its share of project costs. These efforts have been successful in keeping the project on schedule for both design and funding requirements.

NOXSO is working closely with the DOE project management and contracts personnel to assure that DOE is involved with major decision making and informed of project activities. All project management reports have been prepared and submitted to DOE detailing project status, schedule, costs and labor expended.

3.2 NEPA Compliance

For the Warrick site, the location of the NOXSO Plant and Sulfur Recovery Unit (SRU), the data needs identified last quarter were satisfied and the EIV was updated to include this information. No key issues or concerns which may affect NEPA approval were identified. This portion of the EIV has been issued for review to Alcoa Generating Corporation (AGC). Comments from AGC are expected by 3/24/95 and will be incorporated into the final EIV.

Olin Chemicals Charleston plant has been chosen as the host site for the liquid SO_2 plant. The Calabrian Process has been chosen as the liquid SO_2 production process. The Calabrian Process, as discussed in Section 3.4.1, is an advanced liquid SO_2 production process designed for ease of operation and maintenance and to minimize process waste streams and emissions to the environment. Preliminary engineering analysis of the process has eliminated a concern about SO_2 emissions; it is estimated the plant will have SO_2 emissions of less than 1 lb/yr.

With the identification of the liquid SO_2 plant host site and process technology, the data needs identified during the last quarter have been fulfilled and a draft version of the Charleston portion of the EIV is being prepared.

3.3 Front End Engineering - NOXSO Plant

3.3.1 Process

<u>3.3.1.1 PFD</u>

The process flow diagram (PFD) and the piping & instrumentation diagrams (P&IDs) are being updated to reflect the design conditions of the NOXSO Demonstration Plant. Following the completion of this update, and the completion of the mechanical layout and design of the plant, these documents will be scrutinized during the HAZOP procedure, which is discussed below. Following the completion of this review, the PFD and P&IDs will be revised, based on the results of the HAZOP, and released as issued for construction.

The process flow diagram (PFD) has been revised to reflect the heat and material balances based on the existing conditions at the Warrick Power Plant and the process revisions discussed in Quarterly Technical Progress Report #15. The revised PFD was approved by NOXSO Corporation in February, 1995. Any revisions required prior to the HAZOP procedure will be documented in order to be considered during that exercise. Following the HAZOP, the final PFD will be issued for construction.

3.3.1.2 P&ID's

The P&IDs were issued for approval by MK-Ferguson (MK) in early February, 1995, and are presently undergoing internal review by NOXSO. It is anticipated that the review process will be completed by the end of March. Revisions will be presented to MK on an ongoing basis, so that the P&IDs will be updated in a timely manner. The updated P&IDs will be complete pending the HAZOP review. Several process revisions will be included in the updated P&IDs, the revisions that have been completed to date are discussed below.

Flue gas isolation dampers will not be installed in the existing flue gas duct due to the impact that this would have on the Warrick operating permits. In order to quantify any flue gas by-passing and/or recycling, flow meters will be installed in the section of duct between the flue gas inlet and outlet breachings.

The slide gate valves on the downcomer side of the sorbent heater/regenerator L-valve and the regenerator/sorbent cooler L-valve will be manual valves and may possibly be eliminated during the HAZOP review. The riser slide gates for these services are to be located at the top end of the riser in the horizontal run and the slide gate is tentatively set to be at the bottom of the line. This would cause the slide to rise through any sorbent laying on the bottom of the line as it closes, and will be less likely to crush the sorbent. However, this must be weighed against the possibility of sorbent blocking the operation of the valve.

The design and placement of the gas analyzer system has not been finalized; however, all of the dual 2-inch sample ports will be replaced with single 4-inch sample ports with blind flanges. The dual 2-inch sample ports were required at the Proof-of Concept test facility (POC) due to the use of Mott filter probes, which experienced plugging and various other problems. The 4-inch sample ports of the demonstration plant will be used for extractive sampling, and will be available for use by other testing procedures, for example, helium trace tests to verify gas flow rates.

Broken bag detectors were added to the baghouse exit streams, and level detectors were added to the dust hoppers. Various other instruments (e.g. differential pressure transmitters, thermocouples, and sorbent sample points) were either added, deleted, or relocated, the most significant change so far, was in the regenerator, where 20 thermocouples have been reduced to 12.

Also in the regenerator and steam disengaging vessel, the number of manways have been reduced from six to three, and all but one corrosion coupon rack has been deleted. The lone corrosion coupon rack will be used to test various ceramics in the regenerator.

HAZOP Procedure

The HAZOP technique is used on the process when the PFD and P&IDs are sufficiently complete to define the process operations, including all control loops, controlling devices, relief devices and control philosophy. The object of the HAZOP procedure is to identify and rectify any areas in the plant design which might compromise worker safety and/or plant reliability. The HAZOP evaluation examines four distinct operating modes:

a. Start-up (unsteady state)
b. Normal steady state operation
c. Reduced steady state operation
d. Shutdown (unsteady state)

The HAZOP procedure generally lasts several days; it is anticipated that the HAZOP procedure will be completed by early May, 1995. Results of the analysis will be incorporated into the design prior to issuing drawings for construction.

3.3.1.3 Laboratory Fluid-Bed Adsorber Model

The schematic of the steel Multi-stage Fluid-bed Reactor (MSFBR) is shown in Figure 3-1.

The construction of the steel MSFBR is currently underway. Ninety percent of the construction material is ordered. The gas injection system, gas bottles, regulators and miscellaneous flue gas related material is currently in the ordering and final design phase.

The laboratory test matrix for the two-stage adsorber was prepared and is shown in Table 3-1. Initial tests (columns 1 and 2) will duplicate test conditions from the POC. After it has been demonstrated that POC conditions can be satisfactorily matched, demonstration plant conditions will be tested (tests 3 through 6).

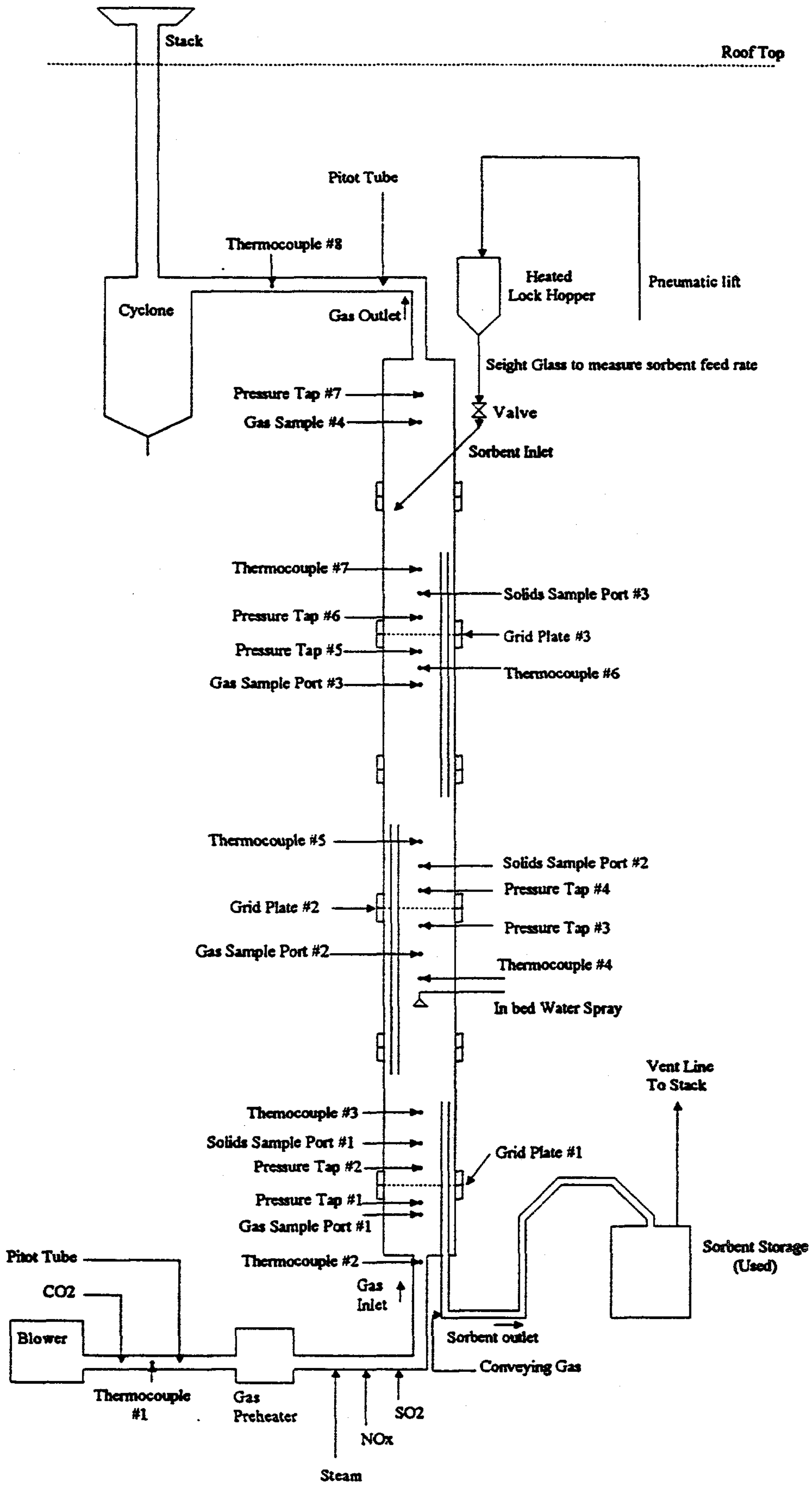


Figure 3-1 Schematic of Steel Multi-stage Fluid-bed Reactor

Table 3-1. LABORATORY TEST MATRIX FOR TWO-STAGE ADSORBER

	PO	Lab	Demonstration
Adsorber diameter (ft)	10.5	0.833	43.5
Adsorber area (ft2)	86.6	0.55	1486
Sorbent density, lbs/ft3	35	35	35

Test Number	1	2	3
Field Conditions			
Flue gas flow rate, scfm	8135	8061	191000
Flue gas flow rate, acfm	12420	10737	259680
Solids flow rate, lbs/h	7454	7453	193542
Superficial gas velocity, ft/s	2.39	2.07	2.90
Bottom bed height, ft	1.00	1.04	1.6
Top bed height, ft	0.81	1.08	1.6
Bottom bed temperature, deg F	361	251	275
Top bed temperature, deg F	358	259	275
Bottom bed gas residence time, sec	0.50	0.60	0.66
Top bed gas residence time, sec	0.41	0.63	0.66
Bottom bed solids residence time, min	24.4	25.4	25.9
Top bed solids residence time, min	19.8	26.3	25.9
SO2 inlet concentration, ppm	2212	1678	2440
NOx inlet concentration, ppm	353	358	768
Sorbent sulfur loading @ 100%	1.22	0.92	1.22

LAB DATA (Scaled down from field condition data)	1	2	3	4	5	6
Flue gas flow rate, scfm	51	51	69	69	69	69
Flue gas flow rate, acfm	78	68	94	98	91	88
Solids flow rate, lbs/h	47	47	71	71	71	71
Superficial gas velocity, ft/s	2.38	2.08	2.89	2.99	2.79	2.69
Bottom bed height, ft	1	1.04	1.6	1.6	1.6	1.6
Top bed height, ft	0.81	1.08	1.6	1.6	1.6	1.6
Bottom bed temperature, deg F	361	251	275	300	250	225
Top bed temperature, deg F	358	259	275	300	250	225
Bottom bed gas residence time, sec	0.50	0.60	0.67	0.64	0.69	0.71
Top bed gas residence time, sec	0.41	0.62	0.67	0.64	0.69	0.71
Bottom bed solids residence time, min	24.4	25.3	25.8	25.8	25.8	25.8
Top bed solids residence time, min	19.7	26.3	25.8	25.8	25.8	25.8
SO2 inlet concentration, ppm	2212	1678	2440	2440	2440	2440
NOx inlet concentration, ppm	353	358	768	768	768	768
Sorbent sulfur loading @ 100%	1.21	0.92	1.20	1.20	1.20	1.20

3.3.1.4 Regenerator Computer Model

During this quarter, the chemistry and kinetic model used in the regenerator computer simulation was revised. The modification was begun when the concerns about sulfur vapor interference in SO_2 measurements made by mass spectrometer during POC testing. All the POC regenerator off-gas concentrations were measured using a mass spectrometer, which detected the species by their molecular weight. Because the elemental sulfur, S_2, and sulfur dioxide have similar molecular weights, the mass spectrometer cannot distinguish S_2 from SO_2. Several particle filters were installed in the POC regenerator, off-gas sample line to prevent sorbent and sulfur particles from entering the mass spectrometer. However, the effectiveness of filters to block sulfur vapor was not confirmed. To revise the regeneration chemistry and kinetics, a computational moving-bed regenerator model was developed on a personal computer. The model used a nonlinear regression program as a subroutine to fit the POC data with the revised reaction model.

The reaction model was subject to the following constraints:

1) All the reaction rate constants must be positive.
2) The model should predict no CO and around 1.5% H_2 in the off-gas.
3) The model should report a vessel heat loss coefficient which is very close to the vessel's design value.
4) The model should give a good agreement between the measured and simulated sorbent temperature, sorbent sulfur content, and off-gas CH_4, CO_2, H_2O, H_2S, COS and CS_2 concentrations.
5) The sum of the simulated SO_2 and S_2 concentrations should be equivalent to the mass spectrometer measured SO_2 concentration.

The 1.5% hydrogen constraint was picked for two reasons. First, the formation of hydrogen in the regenerator off-gas was detected during earlier POC tests, but its concentration was very low, around 0.1%, and sometimes undetectable. Because of the low values, the hydrogen concentration was not measured in later POC tests. Since the POC regenerator off-gas sample contained steam from the top J-valve, the measured hydrogen concentrations were actually diluted with steam. Thus, the real hydrogen concentrations should be higher than those measured. Second, during the life-cycle methane regeneration tests conducted at PETC about 1.5% hydrogen was found in the regenerator off-gas on a nitrogen free basis. Nitrogen was a diluent used in PETC tests for safety reasons.

The steam reforming reaction, which converts CH_4 and steam to CO and H_2, was ruled out because of two reasons. First, no CO was detected during the POC tests. Second, the sorbent temperature in the regenerator is below 1150°F which is below the temperature at which the steam reforming reaction begins.

After extensive data correlation, twelve reactions were selected to describe the regeneration chemistry. These reactions are listed in the following.

(1) $H_2S + Na_2SO_4 + Al_2O_3 \rightarrow 2\ NaAlO_2 + SO_2 + H_2O + 1/x\ S_x$
(2) $2\ H_2S + SO_2 \leftrightarrow 2\ H_2O + 3/x\ S_x$
(3) $H_2 + Na_2SO_4 + Al_2O_3 \leftrightarrow 2\ NaAlO_2 + SO_2 + H_2O$
(4) $3\ H_2 + SO_2 \leftrightarrow H_2S + 2\ H_2O$
(5) $H_2 + 1/x\ S_x \rightarrow H_2S$
(6) $COS + H_2O \leftrightarrow H_2S + CO_2$
(7) $CH_4 + 4\ Na_2SO_4 + 4\ Al_2O_3 \rightarrow 8\ NaAlO_2 + 4\ SO_2 + CO_2 + 2\ H_2O$
(8) $CS_2 + 2\ H_2O \leftrightarrow 2\ H_2S + CO_2$
(9) $CO_2 + CS_2 \leftrightarrow 2\ COS$
(10) $CH_4 + 4/x\ S_x \leftrightarrow CS_2 + 2H_2S$
(11) $CH_4 + SO_2 \leftrightarrow COS + H_2O + H_2$
(12) $CH_4 + 4/3\ SO_2 \leftrightarrow CO_2 + 2/3\ H_2O + 4/3\ H_2S$

Regeneration starts with methane, which first reacts with the spent sorbent according to reaction 7 to produce SO_2. Then, methane reacts with SO_2 and forms H_2 and H_2S as shown in reactions 11 and 12. Methane, hydrogen and hydrogen sulfide regenerate the spent sorbent in accordance with reactions 1, 3 and 7.

The reaction heats, Gibbs free energies, and equilibrium constants for the 12 reactions are listed in Table 3-2.

All the proposed Na_2SO_4 reactions (1,3, and 7) have positive Gibbs free energies and equilibrium constants less than one. A positive Gibbs free energy means that the reaction is thermodynamically unlikely. Since regeneration happens, the alumina and associated hydrates must play some role in facilitating regeneration. For example, reaction 3 can be rewritten with various hydrate forms to make Gibbs free energy negative. Some alternatives to reaction 3 are listed in Table 3-3, which also contains the reaction heats and Gibbs free energies.

Although the moles of H_2O produced is increased to balance the hydrates, the stoichiometric ratio between H_2 and Na_2SO_4 remains the same. Because of the unchanged stoichiometric ratio the POC data can be correlated with any alternate forms. To avoid guessing the number of hydrated waters, reactions without hydrates were used in the regeneration model. This approach is only valid for the isothermal data. To correlate the sorbent temperature, a correct reaction form is needed to calculate the heat of reaction. However, this constraint was used as a criterion to validate the proposed reaction model. The computer program calculated the reaction heats according to the proposed regeneration chemistry, then adjusted the vessel heat loss coefficient to fit the sorbent temperature. The best-fit vessel heat loss coefficient was next checked with

Table 3-2 Reaction Heats, Gibbs Free Energies, Equilibrium Constants of the Regeneration Reactions

Reaction	Reaction Heat, kcal/mol	Free Energies, kcal/mol	Equilibrium Constant
1	75.917	25.915	3.257e-7
2	11.384	-1.623	2.548
3	54.45	14.657	2.143e-4
4	-53.018	-35.397	7.253e+8
5	-21.467	-11.258	6.578e+2
6	-7.462	-6.870	5.244e+1
7	262.693	58.056	2.933e-15
8	-16.677	-17.703	2.7e+4
9	-1.753	-3.963	9.818
10	-24.3	-27.902	9.650e+6
11	-0.664	-29.100	1.925e+7
12	-25.798	-47.769	9.069e+11

Table 3-3 Alternatives for the Hydrogen Regeneration Reaction

Possible Reaction Form	Reaction Heat, kcal/mole	Free Energy, kcal/mole
$H_2 + Na_2SO_4 \dashrightarrow Na_2O + SO_2 + H_2O$	96.386	58.607
$H_2 + Na_2SO_4 + Al_2O_3 \dashrightarrow 2NaAlO_2 + SO_2 + H_2O$	54.45	14.657
$H_2 + Na_2SO_4 + Al_2O_3.H_2O \dashrightarrow 2NaAlO_2 + SO_2 + 2H_2O$	75.651	0.391
$H_2 + Na_2SO_4 + Al_2O_3.3H_2O \dashrightarrow 2NaAlO_2 + SO_2 + 4H_2O$	87.993	-36.835
$H_2 + Na_2SO_4.10H_2O + Al_2O_3 \dashrightarrow 2NaAlO_2 + SO_2 + 11H_2O$	123.75	-142.357

the design value to verify the model accuracy. Because the best-fit vessel heat loss coefficient is 9.7e-6 cal/sec.cm^2.°C which is very close to the design value of 9.5e-6 cal/sec.cm^2.°C, reactions 1 through 12 are accepted as the final model. However, the questions regarding the positive Gibbs free energies of the Na_2SO_4 reactions remain unresolved. The determination of the real solid reactants is beyond the scope of present work.

The accuracy of the regenerator computer model is subject to the data quality. Figure 3-2 shows the relationship between measured and simulated data. For early data, the model predicted sulfur conversions very close to those measured. For later data, the quality of fit becomes worse, as does the measured sulfur balance closure.

The computational moving-bed regenerator model was considered mature. It was used to simulate the regeneration with cocurrent or countercurrent gas/solid flow. POC operation conditions were used in the computation. The off-gas H_2S/SO_2 ratios of these two flow patterns are shown in Figure 3-3. Obviously, the cocurrent flow is superior to the countercurrent in promoting the off-gas H_2S/SO_2 ratio. However, the real advantages of one flow pattern over the other must be decided by the cost analysis, because the cocurrent flow consumes more methane and produces less sulfur than the countercurrent flow.

3.3.1.5 Fluid Bed Flow Modelling

During this quarter the work of fluid bed modeling is to study the effect of grid supports on the gas flow inside the fluid bed vessel. Figure 3-4 shows the position of grid plates and their supports. The grid plates sit perpendicularly on top of the supports, which are 12.78 inch (32.5 mm) wide I-beams. These I-beams reduce the area for gas flow. As a result, the gas accelerates when it flows toward the I-beams. The acceleration of gas increases the sorbent entrainment and distorts the gas distribution beneath the grid plates. Two concerns were raised during the earlier fluid-bed design. One, the entrained sorbent will impinge upon the grid plate then block the perforated holes. Two, the gas may not distribute itself uniformly before reaching the grid plates. To get a quantitative answer, Computational Fluid Dynamics software was used to simulate the gas flow pattern between the two grid plates.

The CFD simulation assumes a 2-dimensional flow with a uniform inlet gas velocity of 3.3 ft/s (1 m/s). Because of the symmetrical arrangement, only the gas around one half of the I-beam was considered. Figure 3-5 is the plot of gas velocity vectors between the two grid plates. As expected, the gas velocity increases when the gas flows over the I-beam. Circulating flow occurs between the I-beam flanges as well as downstream of the I-beam. After flowing over the I-beam, the gas redistributes itself toward the downstream grid plate. The maximum gas velocity around the I-beam is 5.9 ft/s (1.8 m/s) which is equal to the terminal velocity of 425 μm particles. Since the size of perforated holes is nine times larger than 425 μm, blockage of grid plate holes is not a concern.

Figure 3-2. Data Quality and Simulation Results

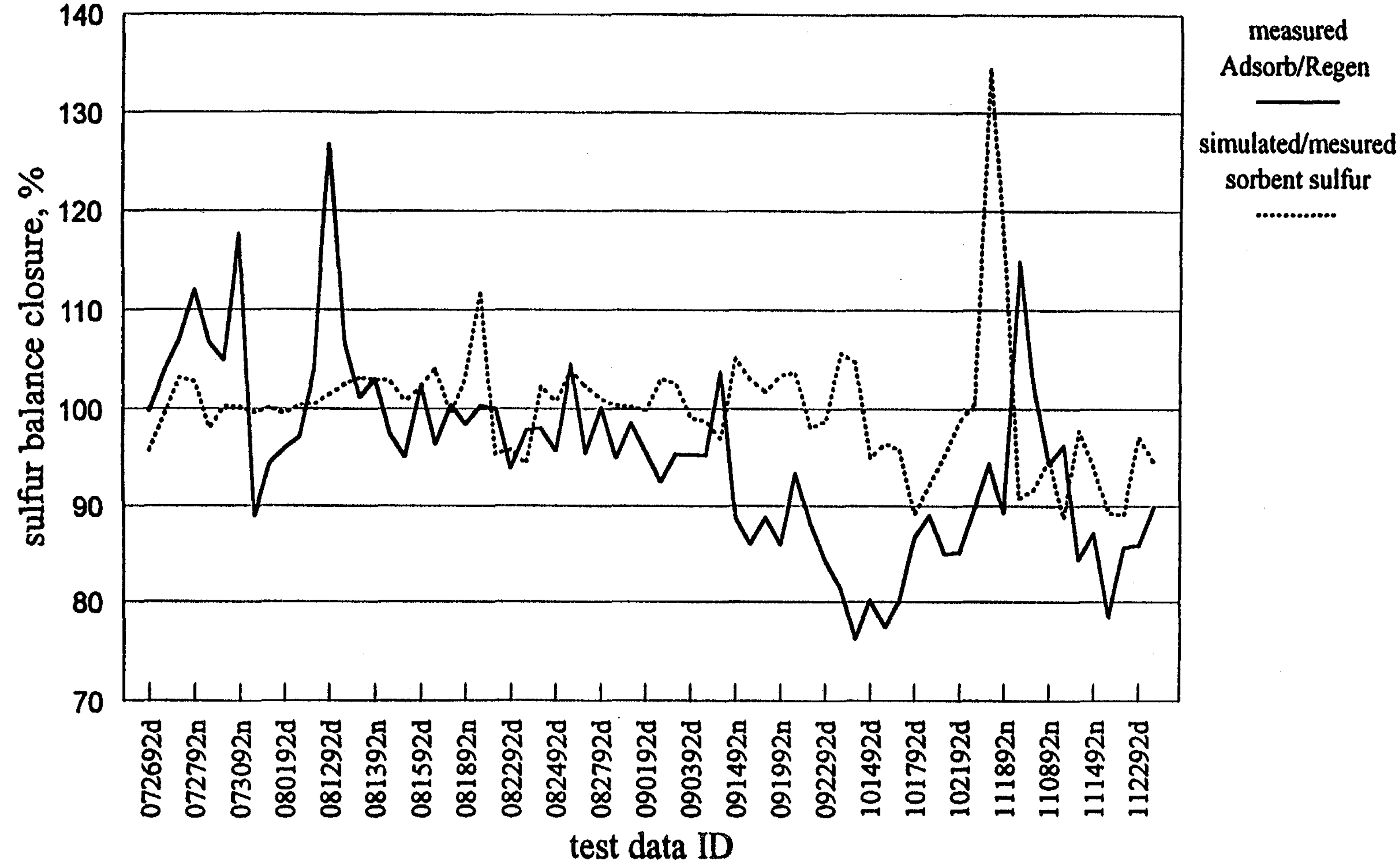
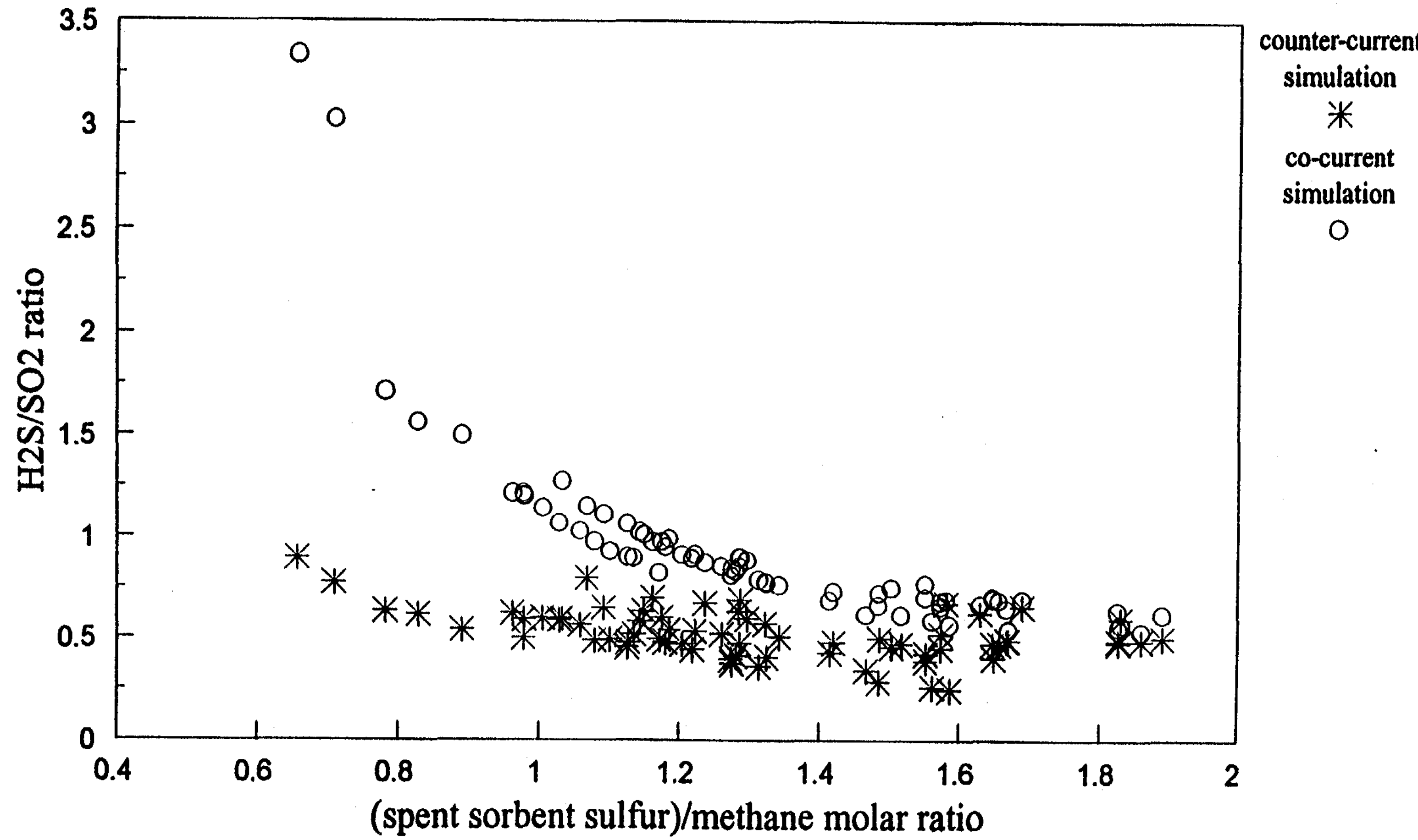


Figure 3-3. Comparison of H2S/SO Ratio between the Cocurrent and Countercurrent Moving Bed



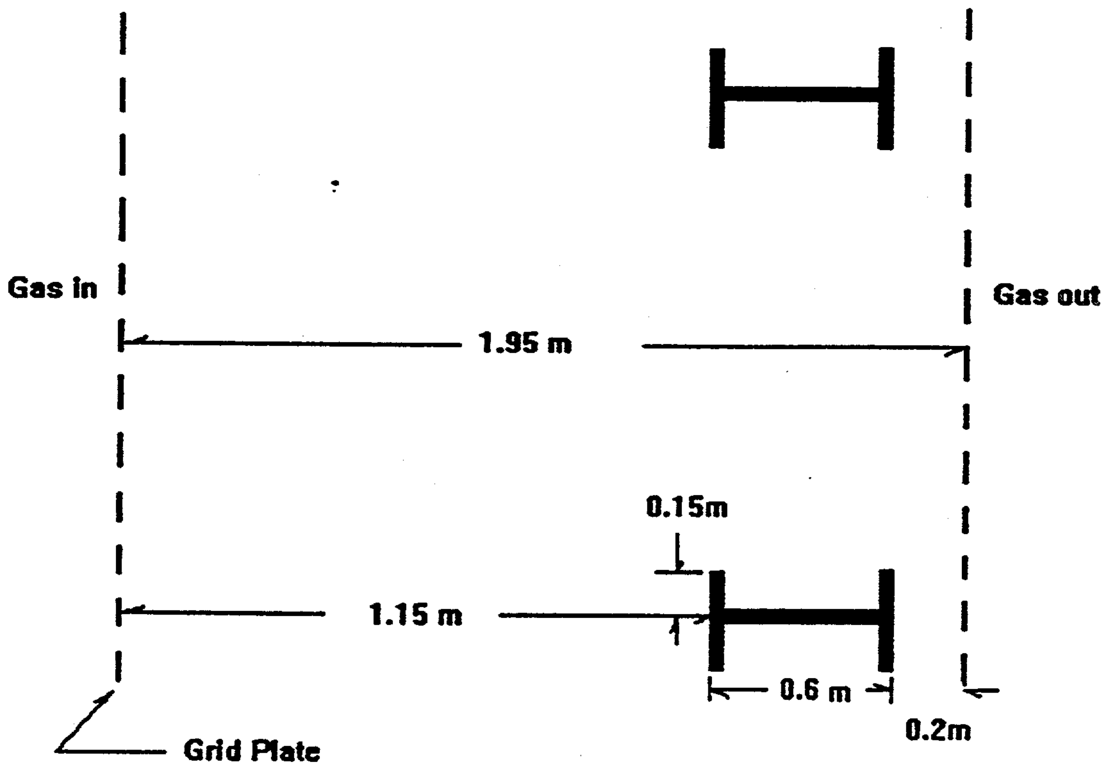


Figure 3-4 Fluid-bed Grid Plate and Grid Support

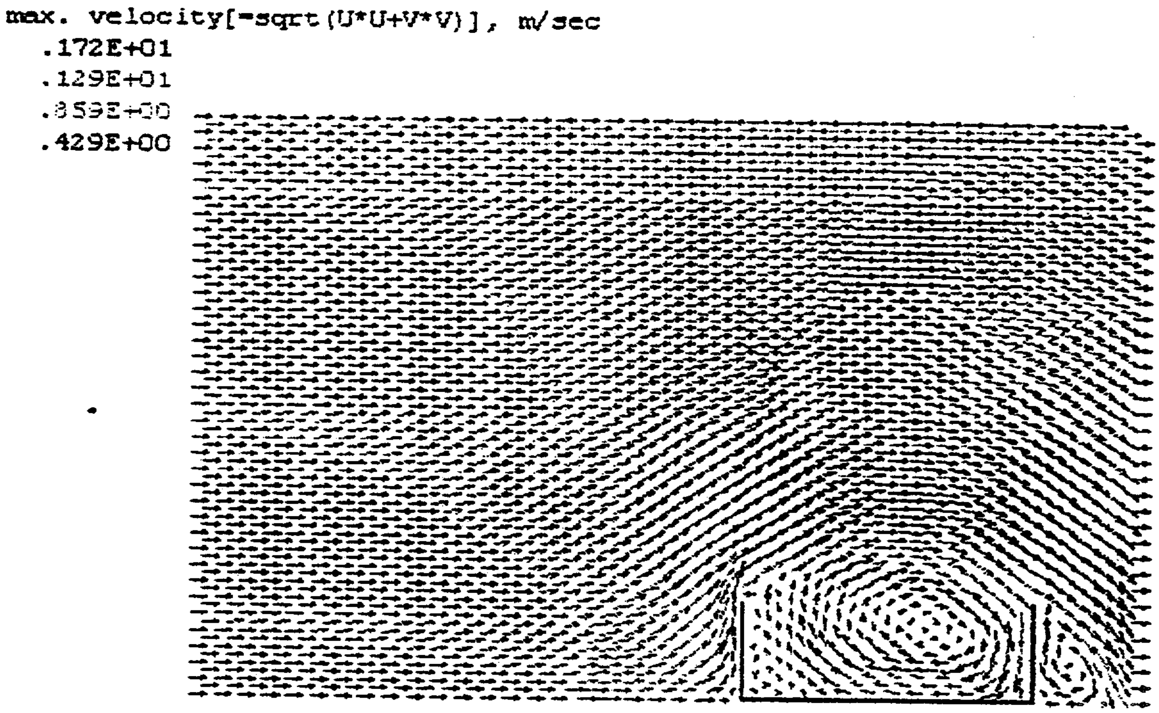


Figure 3-5. Velocity Vectors between Two Grid Plates

3.3.2 Civil/Structural

3.3.2.1 Undergrounds

The following is a brief update on the status of the locations and consequences of underground lines in the project site area, and the preliminary foundation and structure designs required to support the process vessels and ductwork.

All of the underground lines in the vicinity of the NOXSO plant and the sulfur plant have been consolidated onto one drawing. Each line has been identified and labelled in terms of its service and availability for rerouting. Abandoned lines have also been identified. No problems are foreseen in rerouting any necessary lines. The lines which are required to be rerouted will be identified as the site layout is revised.

Preliminary foundation designs for the adsorbers, the regenerator/steam disengaging vessel, and the transformer have been completed based on the 1982 Geotechnical report prepared for Unit 4 of the Warrick Power Plant. The designs will be updated with the results of the present study.

A preliminary framing layout for the sorbent cooler/sorbent heater tower has been completed. The top of the structure is currently 90 feet high. Structural design of the duct supports has also begun. It is estimated that there will be 17 duct support towers, preliminary layouts for 3 have been completed. The foundations will be designed and all of the structural designs will be updated based on the results of the present Geotechnical study.

Once the site survey is complete, the NOXSO plant layout can be finalized. Once the Geotechnical report is completed and the site layout is finalized, the foundations and steel structures can be updated and completed.

3.3.2.2 Site Survey

A survey of the areas where the NOXSO plant, the main transformer and switchgear and rail siding location is required. The purpose of the survey is to provide vertical and horizontal locations of all buildings, pipelines, conveyors, ductwork, powerlines, etc. in the affected areas. A topographical survey of these areas is also required. The purpose of the survey is to provide accurate data to allow siting of the plant, transformer and switchgear and routing of the rail siding with minimum impact on the existing facilities and minimum construction costs.

MK-Ferguson prepared a specification for survey work, a scope of work and a request for quotation for survey services. Four companies were solicited to provide proposals to perform the required work, three quotations were received. Based on competitive cost, the recommendation of MK-Ferguson and the recommendation of Alcoa, Morley and Associates of

Evansville, IN was chosen by NOXSO. The work scope was increased to include the switchyard and proposed route of the rail siding.

NOXSO issued a purchase order to Morley and Associates on February 9, 1995. The field work was completed in February. The deliverable drawings are expected in early March.

3.3.2.3 Rail Siding

A rail siding is required to ship the sulfur from the NOXSO plant. The siding will run from the NOXSO plant around the west end of Alcoa's power plant and join a track in the rail yard north of the power plant. Norfolk Southern proposed two possible routes from the railyard to the vicinity of the NOXSO plant. Both routes had curves that did not exceed 15 degrees. In railroad terminology the degree of curvature is defined as a central angle subtended by a chord 100 feet long. Neither of the routes proposed by Norfolk Southern were acceptable. One route ended approximately 500 feet from the NOXSO plant which would require pumping molten sulfur that distance. The other route did run all the way to the location of the NOXSO plant but joined the Alcoa railyard at a point that required moving the sulfur cars through Alcoa's engine maintenance building.

The proposed route of the siding is a hybrid combination of the two routes proposed by Norfolk Southern. This route will have a 17 degree curve which exceeds Norfolk Southern's published limits for curvature for operating their main line engines. However, a Norfolk Southern representative has stated that they have maneuvered their engines on 18 degree curves. While the plan is to use Alcoa's yard engines to move sulfur cars on the siding and into the railyard, it is desirable to have the ability to use a Norfolk Southern engine on the siding should the need arise.

After the survey drawings are received the rail siding design will either be added to MK-Ferguson's scope of work or it will be let as an independent subcontract to some other qualified company. It is anticipated that this will be done in early April.

3.3.3 Mechanical

3.3.3.1 Site Plan

The site layout discussed in Quarterly Technical Progress Report #15 presented the NOXSO plant battery limits and the preliminary site layout. The NOXSO plant battery limits were defined in relation to the power plant while the preliminary site layout located the major process vessels within the battery limits. The locations of the major process vessels have been chosen to minimize the amount of ductwork required and to minimize the lengths of the L-valve horizontal runs.

While the battery limits and preliminary vessel layout have not changed, Figure 3-6 presents a view of the NOXSO plant relative to Warrick Units 1, 2, and 3, providing an updated view of the NOXSO site plan. The changes from the previous site plan include the inclusion of the sulfur plant and rail spur in their preliminary locations, and the relocation of the analyzer, process control, and motor control center buildings from the west side of the site to the east side of the site. The sulfur plant is located as close to the regenerator as possible in order to minimize the lengths of the sulfur lines, and the buildings have been relocated in order to keep the west side of the site open for sorbent delivery trucks as well as separating these buildings from the sulfur plant area for safety.

Also included is the preliminary location of the unit substation, and a change in the location of the air compressors, air dryers, and the heater/cooler fans. Following the analysis of the results of the site survey and the geotechnical investigation, the site layout will be finalized and the auxiliary equipment will be placed to minimize the effects of their locations on piping, wiring, and unit accessibility.

3.3.3.2 Process Vessel Designs

The detailed designs of the major process vessels and their internal structures are nearing completion, with mechanical specifications, drawings and detailed vessel design calculations being prepared for vendor bid packages. The major process vessels are the fluid-bed vessels: the adsorbers, sorbent heater, and sorbent cooler; and the steam disengaging vessel and regenerator, which are moving-bed vessels. The preliminary designs, including vessel dimensions and operating conditions, have been discussed in Quarterly Technical Progress Report #15.

The major process vessels have been designed according to the ASME Boiler and Pressure Vessel Code, Section VIII, Division 1. Although none of the vessels are required to carry the Code stamp, following the Code assures that the vessels will be designed and built according to the highest quality standards.

Vessel internals include the grids, grid supports, downcomers, and flapper valves in the fluid-bed vessels, and sparger rings in the regenerator. All vessel internal structures have been designed in accordance with the American Institute of Steel Construction (AISC) Steel Construction Manual; Code of Standard Practice.

The current designs of the auxiliary process vessels are also discussed. The auxiliary process vessels include the surge bins and the sorbent storage bin.

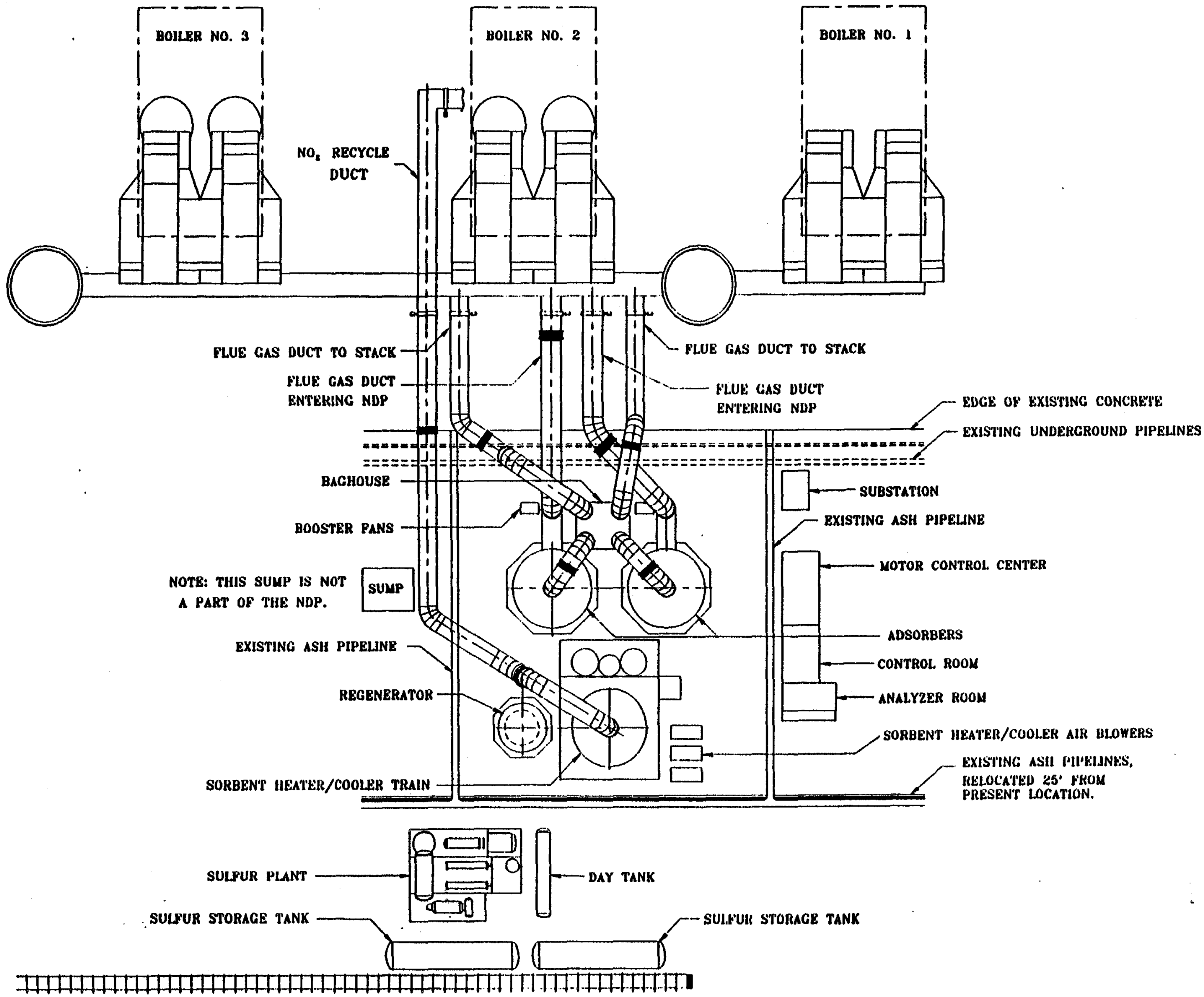


Figure 3-6 NOXSO Site Plant Layout

Adsorbers

The purpose of the adsorbers is to contact flue gas with NOXSO sorbent in a multi-stage, fluid-bed reactor. The demonstration plant has two adsorbers to handle the volume of flue gas and to provide adequate turndown capabilities. Operating and design conditions, the general configuration, and preliminary vessel dimensions have been presented previously. As expected, due to the relatively low design temperature and pressure, the detailed design of the adsorbers was the least difficult of the major vessels, and will not use refractory lining or exotic materials of construction. A request for quotation for the fabrication and construction of these vessels has been issued during this reporting period.

All of the vessel shell components: the top head, the cylindrical section, the bottom head, and the support skirt, will be fabricated from 1/2" carbon steel plate. Shell thicknesses were calculated assuming a joint efficiency of 0.85, for spot radiography, except for the vessel skirt which uses a joint efficiency of 0.55 (the maximum allowable joint efficiency for the type of welded connection used to attach the skirt to the shell). Based on the predicted collapse pressure of the 2:1 elliptical heads, and the design and operating pressures, there is a factor of safety against collapse of 6:1 on the design conditions, and 14:1 on the operating conditions.

As reported previously, the adsorbers have been designed for three sorbent stages, but will only be constructed with two; a third stage will be added later in the demonstration program if preliminary research warrants testing. Any nozzles associated with the third grid will be blinded until used.

Adsorber Internals

The design and installation of the adsorber grid plates and supports will essentially follow the description presented in Quarterly Technical Progress Report #15. The grids in the adsorbers will be supported by six WF21 x 132 carbon steel beams. The support shoes for these beams are welded to 30 inch square reinforcement pads. The support beams have been designed for a maximum deflection of 0.83 inches. To prevent sorbent from accumulating in the center of the grid, allowing gas by-passing around the edges, a maximum value of 5% of the settled sorbent bed depth has been assigned as the maximum beam deflection. In the adsorbers, where there are 18" sorbent beds (settled bed height), the maximum allowable deflection for process considerations is 0.9 inches. From a structural standpoint, the AISC limits the maximum beam deflection to the span divided by 360. The AISC maximum beam deflection is 1.43 inches, thus the beams are in compliance with both of these requirements as designed.

Sorbent Heater

The purpose of the sorbent heater is to raise the sorbent temperature from 275 to 1150°F prior to regeneration. The preliminary design discussed in Quarterly Technical Progress Report #15 suggested that the sorbent heater would employ either a cold wall (all internal refractory) or hot wall (all external insulation) design. The initial concern with the warm wall design (a combination of internal refractory and external insulation) was that preliminary heat transfer calculations showed that with insulation on both sides, the shell temperature would rise above 1200°F in some places, negating the benefit gained by the refractory lining on the allowable stress within the shell. Subsequent discussions with refractory suppliers have led to a design which uses an all carbon steel shell, with approximately 9" of internal refractory lining from the bottom head to the top grid, and at least two inches of external insulation on the entire vessel. This design allows the metal to operate at a temperature below the creep range, minimizes the thermal expansion of the shell, and allows the shell to provide structural stability to the vessel and its internals.

The vessel specification and preliminary vessel drawings and detailed calculations have been prepared in enough detail to be submitted with a request for quotation. While this information is incomplete, a follow-up package including additional details on the vessel internals will be completed soon. It is believed that the design is complete enough for vendors to have adequate information to formulate bids. The additional details will be submitted to the bidders as they become available.

The design calls for an all carbon steel shell fabricated from 3/4" plate. While this is thicker than code calculations require, the shell has been oversized in order to support the grids through external support boxes without requiring local reinforcement pads for the 56 nozzles. A manway to provide access to the bottom head has been designed into the bottom grid instead of the bottom head. This is the most economical approach, considering the refractory lining.

Sorbent Heater Internals

The design details on the downcomers (including the sorbent outlets), grid supports, and grid sealing are currently incomplete, but the basic design philosophy is as follows. The grid design is unchanged. The bottom three sets of grid support beams are supported 'externally' in support boxes attached to the vessel's carbon steel shell. The ends of the beams nearest the downcomers are rigidly attached to the boxes, while the other ends are permitted to expand by sliding along support ledges. The bottom downcomers will have expansion joints to account for the motion of the grids in relation to the fixed sorbent exit points. All of the grid support beams are stainless steel, in order to adequately support the loads with reasonably sized beams. The bottom grid support boxes are stainless steel, for strength at temperature, and the center two grid support boxes are carbon steel. The top grid is supported using a method similar to the adsorber grids.

Sealing the grid periphery from gas and/or sorbent bypassing is being carefully considered. The sealing will use refractory ledges on the bottom to allow for expansion, while along the top there will be a resilient sealing ring. The other concern is the accumulation of sorbent fines in inappropriate places, such as the expansion gaps. While the design will make every attempt to prevent this, one alternative being considered is the use of inspection openings in the grid support boxes. These openings could be accessed during shutdown to insure clean expansion spaces prior to heat up. Details of the internal design will be completed during the coming quarter.

Sorbent Cooler

The purpose of the sorbent cooler is to reduce the temperature of the sorbent from 1050 to 300°F prior to being returned to the adsorbers. After careful consideration of the impacts on vessel cost and performance, the sorbent cooler will use a hot wall design. The top half of the vessel, in the high temperature region, will be fabricated from stainless steel plate, and the bottom, cooler half of the vessel will be fabricated from carbon steel plate. The vessel from the bottom head to the third grid from the bottom will be 1/2" carbon steel. The area from this transition point to the top head tangent line will be 3/8" stainless steel, while the top head will be 1/2" stainless steel. The chrome-moly/carbon steel design of the POC sorbent cooler will not be repeated because chrome-moly steel requires post-weld heat treatment, which makes field assembly impractical. The entire vessel will have external insulation to maintain a skin temperature of 130°F. The design, including details of the vessel internals, will be completed and submitted for bids early in the coming quarter.

Steam Disengaging Vessel and Regenerator

The purpose of the steam disengaging vessel is to separate the top L-valve steam from the sorbent prior to its introduction to the regenerator. The purpose of the regenerator is to contact sulfur laden sorbent with natural gas followed by contact with steam to remove the sulfur from the sorbent. These vessels are in a stacked arrangement, with the support skirt of the steam disengaging vessel attached to the shell of the regenerator. The final vessel specification and preliminary copies of the vessel drawings and detailed calculations have been assembled into a request for quotation package and submitted to bidders. Final drawings and calculations are presently being prepared. The vessels are designed as two separate vessels but are assembled as one vessel, thus it is preferable that the same vendor fabricate and construct both of these vessels.

These vessels will employ a cold wall design as discussed in Quarterly Technical Progress Report #8. The internals will be refractory lined, including a layer of chemical resistant shielding to protect the shell in the case of cracks forming in the refractory material. The carbon steel shell will be painted with heat sensitive paint, thus if there is a problem with the refractory lining which causes a hot spot on the shell, it will be visibly apparent. All of the vessel nozzles will also be sized to be refractory lined; however, the distance beyond the vessel boundary that this refractory sleeve must extend has not yet been determined.

Regenerator Internals

The regenerator requires two sets of sparger rings, one to introduce natural gas and one to introduce steam. The purpose of the spargers is to provide a uniform distribution of gas across the vessel cross section. The force of the sorbent in a moving bed prohibits a cantilever design for the spargers so that a more secure support system must be designed into the vessel. The sparger itself will consist of a central header running across the vessel, supported at both ends, with 9 lateral spokes along its length. The ends of the spokes will also be supported, possibly by a refractory ledge which would also allow thermal expansion. Details of this support system will be completed during the coming quarter.

Auxiliary Process Vessels

The auxiliary process vessels are the sorbent surge bins and the sorbent storage bin. The purposes and preliminary designs of these vessels are presented here.

The purpose of the surge bins is to provide a source and sink for sorbent so that levels in all the other process vessels may be kept steady during periods of unsteady sorbent flow. There are two surge bins, one to feed each adsorber. The surge tank design residence time at base case conditions is 20 minutes. During normal operation the surge bins are only half full to provide flexibility. The design of the surge bins uses a cone angle of 50°; solids flow patterns are not critical here so a smaller cone angle is acceptable. The vessel height to diameter ratio is not critical except to make sorbent level measurements easy, thus a ratio of 2:1 is used where the vessel height includes the cone section. The preliminary design of the sorbent surge bins is shown in Figure 3-7.

The purpose of the sorbent storage tank is to provide on site storage of fresh, make-up sorbent, and to store sorbent from the system when it is necessary to inspect or repair other process vessels. The sorbent storage tank is sized to hold enough sorbent such that any other process vessel can be completely emptied, or to hold a two-week supply of make-up sorbent, whichever is greater. In the case of the demonstration plant, the former case controls. While two weeks of make-up sorbent is less than 2000 ft^3, the ability to completely empty the regenerator requires 10,000 ft^3. This size is calculated considering that the steam disengaging vessel must also be

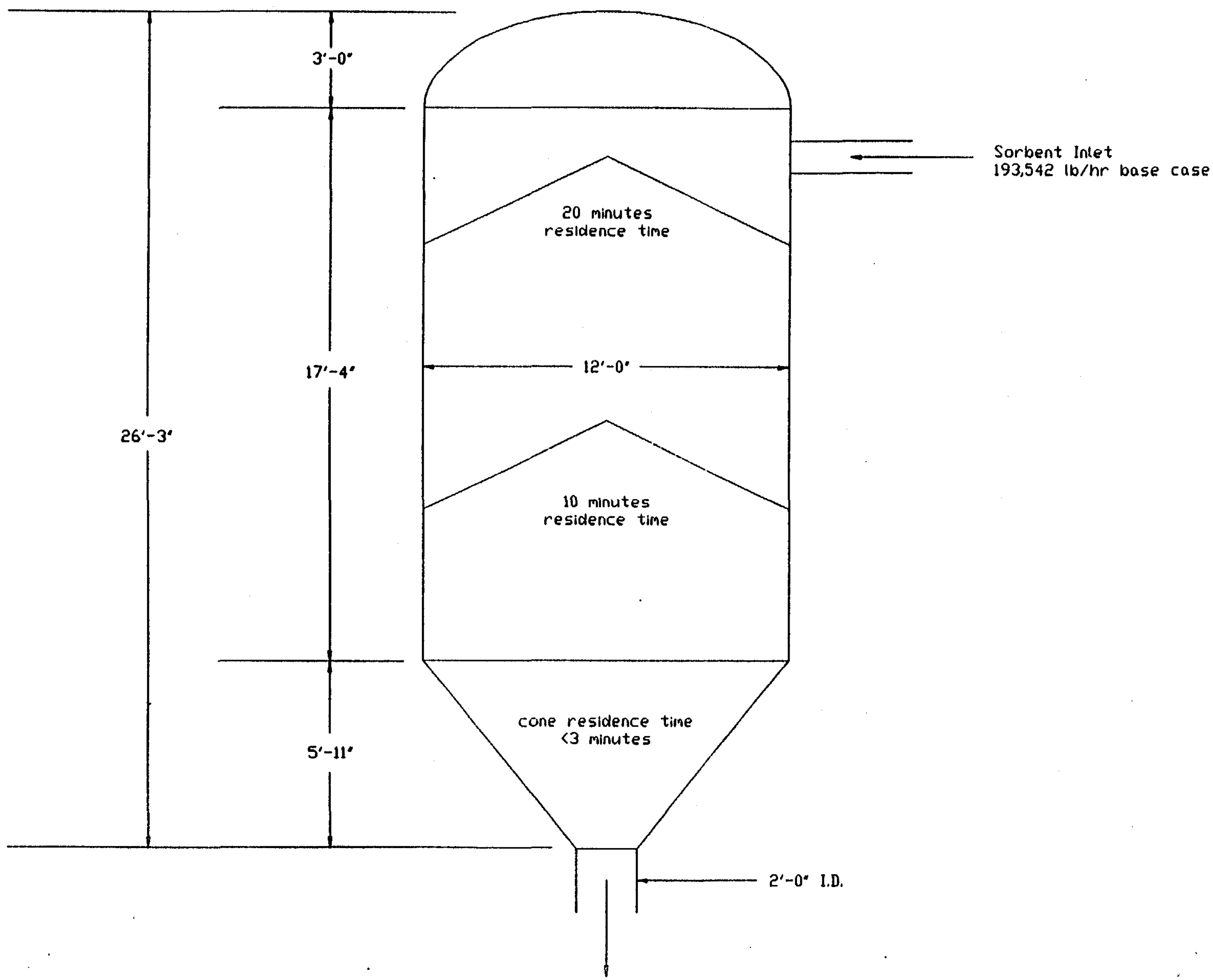


Figure 3-7 Preliminary Sorbent Surge Bin

drained, because there is no isolation valve between the vessels. This is partially off-set by the ability of the fluid-beds to hold additional sorbent when necessary. The additional amount of sorbent which can be temporarily stored in the other fluid-beds is controlled by the available head of the adsorber and cooler fans. The dimensions of the sorbent storage tank, including using multiple tanks, can be adjusted to conform to plant space availability. The tank cone angle is 50°, and the height to diameter ratio is typically 2:1.

3.3.4 Electrical

Power for the NOXSO plant will be provided from the 138 kV ring bus located at the northwest corner of the power plant. A 138 kV to 4160 V transformer and associated breakers and switchgear will be located in the 138 kV switchyard. Several routes are being considered for transmission of the power to the area of the NOXSO plant at the southeast corner of the power plant. Possible routes include; through the power plant, above ground, underground, and combinations of the above. The 480 V substation will be located in the area of the NOXSO plant. The motor control center (MCC) will be located in the area of the NOXSO plant.

3.3.5 Procurement

Procurement activities for the NOXSO demonstration plant were initiated during this quarter. These activities include: preparation of equipment specifications, assembly and submission of requests for quotation, tabulation of received bids, technical evaluation and recommendation. Updates on each of these activities are presented below.

3.3.5.1 Equipment Specifications

Equipment specifications which had been prepared for the demonstration plant at Niles have been updated based on the changes in the site location and the process design. Additional specifications have been or will be prepared as necessary. A list of the specifications required for this project and their status (complete/in progress/incomplete) is provided in Table 3-4. 'In progress' implies that the specification is currently under internal review for technical content, format, grammar, continuity, completeness, and consistency with other project specifications.

All of the specifications prepared for the demonstration project are written in the three-part format of the Construction Specifications Institute (CSI), with minor variations. The five-digit numbering system recommended by CSI has also been used.

The majority of the mechanical specifications have been completed. These specifications are essential to the project cost estimate and to equipment procurement; included in this group are process vessels, pumps, fans, heat exchangers, air compressors, air dryers, expansion joints, pneumatic conveying system, nitrogen supply system, sulfur recovery plant, in-duct air heater,

TABLE 3-4. NOXSO DEMONSTRATION PLANT
SPECIFICATION SUMMARY

TITLE	NUMBER	STATUS	TITLE	NUMBER	STATUS
SURVEY WORK	00200	C	PIPING NOT INTEGRAL WITH EQUIPMENT	15060	C
GEOTECHNICAL WORK	02010	C	FLUE GAS WATER SPRAY PUMP	15160	C
EARTHWORK FOR STRUCTURES	02200	I	INSULATION OF PIPING	15260	C
UNDERGROUND YARD UTILITY PIPING	02700	I	EQUIPMENT AND DUCT INSULATION	15280	C
REINFORCING STEEL FOR CONCRETE	03200	I	INSTALLATION OF PLUMBING EQUIPMENT	15400	P
CAST-IN-PLACE CONCRETE	03300	I	NITROGEN SUPPLY SYSTEM	15482	C
REFRACTORY	04570	P	DUCTWORK	15577	C
STRUCTURAL STEEL FABRICATION	05120	I	ECONOMIZER (NOx RECYCLE COOLER)	15755	C
STRUCTURAL STEEL ERECTION	05125	I	STEAM SUPERHEATER	15758	C
STEEL DECK ROOF	05310	I	CENTRIFUGAL FANS	15860	C
METAL FABRICATIONS	05500	I	CENTRIFUGAL AIR BLOWERS	15861	C
CEMENTITIOUS FIREPROOFING	07255	I	SULFUR RECOVERY PLANT	15889	C
FIRESTOPPING	07270	I	THERMAL EXPANSION JOINTS	15997	C
FLASHING AND SHEET METAL	07600	I	VENDOR REQUIREMENTS FOR ELECTRICAL EQUIPMENT	16005	P
GUTTERS AND DOWNSPOUTS	07631	I	ELECTRICAL WORK	16050	I
JOINT SEALERS	07920	I	NEMA FRAME INDUCTION MOTORS	16076	P
FINISH HARDWARE	08710	I	MEDIUM VOLTAGE AC INDUCTION MOTORS ABOVE 200 HP	16077	I
FINISH PAINTING	09900	I	LOW VOLTAGE WIRE AND CABLES 600 VOLTS AND BELOW	16120	I
BAGHOUSE	11580	C	MEDIUM VOLTAGE (5 KV & 15 KV) POWER CABLE	16122	I
GAS-FIRED IN-DUCT AIR HEATER	11596	C	MEDIUM MOTOR STARTERS	16190	I
PACKAGED CENTRIFUGAL AIR COMPRESSORS	11654	C	LOAD CENTER UNIT SUBSTATION	16310	I
REGENERATIVE TYPE AIR DRYER	11660	C	SUBSTATION STRUCTURES	16311	I
BIN VENT FILTERS	11692	C	POWER TRANSFORMERS	16320	P
MODULES	13021	C	NEUTRAL GROUND RESISTOR	16325	I
FIELD ASSEMBLED LOW PRESSURE PROCESS VESSELS	13200	C	MEDIUM VOLTAGE SWITCHGEAR	16345	I
FIELD ERECTED REACTOR VESSELS	13201	C	OUTDOOR POWER CIRCUIT BREAKER	16350	I
SHOP FABRICATED TANK GRIDS	13205	P	LOW VOLTAGE METAL ENCLOSED SWITCHGEAR	16425	I
ELEVATOR - SPECIAL PURPOSE	14215	C	PRIMARY LOAD INTERRUPTER SWITCH	16440	I
PNEUMATIC CONVEYING SYSTEMS	14553	C	480 V MOTOR CONTROL CENTER	16480	I
PRODUCT STORAGE BINS	14566	C	UNINTERRUPTIBLE POWER SUPPLY	16610	I
GENERAL SPECIFICATION FOR EQUIPMENT	15010	C	LIGHTNING PROTECTION	16670	I
INSTALLATION OF EQUIPMENT FOR PROCESS FACILITIES	15011	C	FIRE ALARM SYSTEM	16721	I
SITE STORAGE AND PROTECTION OF EQUIPMENT	15012	C	ELECTRICAL HEAT TRACING	16865	I
SOUND LEVEL SPECIFICATION FOR EQUIPMENT	15013	C	ELECTRICAL ACCEPTANCE TESTS	16950	I

C - Complete   I - Incomplete   P - In Progress ductwork, piping, and insulation. The only incomplete mechanical specifications are for the fluid-bed grids and the refractory lining, which are currently under internal review.

With the completion of the mechanical specifications, and the establishment of process power requirements, the current emphasis is on the completion of the electrical specifications. These specifications include any motors, starters, transformers, switchgear, circuit breakers, cable, and other power supplies required for the project. As seen in Table 3-4, no electrical specifications are complete, but three are presently being prepared.

The only construction or subcontract specifications completed are those written for the site survey and geotechnical investigation. The remainder deal with work packages concerning the construction of the facility and have not been prepared as of yet.

3.3.5.2 Requests for Quote

Requests for quotation (RFQs) are prepared for each piece of equipment or instrument required for the project. Requests for quotations are prepared after Engineering provides the relevant specifications along with a purchase requisition form to Procurement. Purchase requisitions are internal documents used to transmit instructions and information to Procurement for obtaining equipment, instruments, and materials. Procurement assembles the RFQs and submits them to vendors for bid.

The contents of a request for quotation package include: Instructions to bidders; purchase order general conditions; supplemental conditions; all applicable specifications, drawings, and data sheets; vendor data requirements and instructions; and a request for quotation cover page which provides the bid due date. The status of all of the anticipated requests for quotations is summarized in Table 3-5. "Complete" status implies that the RFQ has been prepared and submitted to vendors, while "incomplete" implies that the RFQ is currently being assembled or under internal review.

3.3.5.3 Bids

Bid tabulation of vendor proposals is required to compare bids and check compliance with specifications, pricing, and delivery of the equipment being quoted. Vendor proposals are requested and received by Procurement. The bids are then submitted together with a tabulation showing price, applicable freight, and delivery dates to Engineering for technical review. A sample bid tabulation form is shown in Figure 3-8. Bid tabulations have been completed for 12 pieces of equipment, as summarized in Table 3-5.

TABLE 3-5. NOXSO DEMONSTRATION PLANT
EQUIPMENT AND INSTRUMENT PROCUREMENT SUMMARY

NUMBER	DESCRIPTION	RFQ	BID TAB	NUMBER	DESCRIPTION	RFQ	BID TAB
C-101	DENSE PHASE CONVEYING SYSTEMS	C	C	K-105	50 PSIG AIR COMPRESSOR	C	C
D-101	REGENERATIVE AIR DRYERS	C	C	K-106	15 PSIG AIR COMPRESSOR	C	C
E-101	NOx RECYCLE COOLER	C	C	MCC-LV	LOW VOLTAGE MOTOR CONTROL CENTER	I	I
E-102	STEAM SUPERHEATER	I	I	MCC-HV	HIGH VOLTAGE MOTOR CONTROL CENTER	I	I
F-101	BIN VENT FILTERS	C	I	OCB-101	CIRCUIT BREAKER	I	I
FX-102	BAGHOUSES	C	C	P-101	ADSORBER WATER SPRAY PUMPS	C	I
H-101	IN-DUCT AIR HEATER	C	C	P-102	NOx RECYCLE COOLER BFW PUMP	C	I
HT-101	HEAT TRACE PANEL	I	I	P-103	SULFUR PLANT BFW PUMP	C	I
I-001	CONTROL DAMPERS	C	I	Q-101	SPECIAL PURPOSE ELEVATOR	C	C
I-002	SLIDE GATE VALVES	C	I	SU-201	SULFUR RECOVERY UNIT	C	C
I-003	ON-OFF BALL VALVES	C	I	SWGR-1	4160 VOLT SWITCHGEAR	I	I
I-004	THROTTLING CONTROL VALVES	C	I	TR-A	138 KV/4160 V TRANSFORMER	I	I
I-005	PRESSURE RELIEF VALVES	C	I	UPS-1	UNINTERRUPTIBLE POWER SUPPLY	I	I
I-006	PRESSURE REGULATORS	C	I	US-1	4160 V/480 V UNIT SUBSTATION	I	I
I-007	VORTEX FLOWMETERS	C	I	V-101	ADSORBERS	C	I
I-008	TURBINE FLOWMETERS	C	I	V-102	SORBENT HEATER	I	I
I-009	PITOT TUBES	C	I	V-103	REGENERATOR	I	I
I-010	ORIFICE PLATES	C	I	V-105	SORBENT COOLER	I	I
I-011	HONEYWELL TRANSMITTERS	C	I	V-106	SORBENT SURGE BINS	C	I
I-012	CAPACITANCE SWITCHES & TRANSMITTERS	C	I	V-107	SORBENT MAKE-UP HOPPER	C	I
I-013	NUCLEAR LEVEL SWITCHES & TRANSMITTERS	C	I	V-109	LIQUID NITROGEN TANK	C	I
I-015	RUPTURE DISKS	C	I	V-110	HIGH PRESSURE AIR RECEIVERS	I	I
I-016	PRESSURE GAGES	C	I	V-111	SORBENT STORAGE BIN	C	I
I-017	PRESSURE SWITCHES	C	I	V-113	DENSE PHASE AIR RECEIVERS	I	I
I-018	TEMPERATURE INDICATORS	C	I	V-115	STEAM DISENGAGING VESSEL	I	I
I-019	TEMPERATURE SWITCHES	I	I	VG-101	ADSORBER GRIDS	I	I
I-020	THERMOCOUPLES & THERMOWELLS	I	I	VG-102	SORBENT HEATER GRIDS	I	I
I-022	PURGE ROTAMETERS	I	I	VG-105	SORBENT COOLER GRIDS	I	I
I-023	OXYGEN SENSOR & ANALYZER	I	I	Z-101	DUCTWORK	I	I
I-024	AMBIENT AIR SENSORS	I	I	Z-102	EXPANSION JOINTS - DUCTWORK	I	I
I-025	RACK MOUNTED ANALYZER SYSTEMS	I	I	Z-103	EXPANSION JOINTS - PIPING	I	I
I-026	JUNCTION BOXES	I	I	NA	DISTRIBUTED CONTROL SYSTEM	I	I
K-101	ADSORBER BOOSTER FANS	C	C	NA	REFRACTORY LININGS	I	I
K-103	COOLING AIR FANS	C	C	NA	VESSEL/DUCTWORK INSULATION	I	I
K-104	100 PSIG AIR COMPRESSORS	C	C				

C - Complete   I - Incomplete   NA - Not Yet Assigned

NOXSO CORPORATION - TABULATION OF BIDS

Equipment Title:__________________ Work Order:________

Requisition No.:__________ Job Name:________________________ Date:________

VENDOR	COST	PAYMENT TERMS	F.O.B. POINT	FREIGHT	DELIVERY	COMMENTS

BIDDERS LIST APPROVED:

Date:__________

Approval:____________________
(SIGNATURE)

RECOMMENDATION:

____

____

Page ___ of ___

Figure 3-8. Bid Tabulation Form

3.3.5.4 Technical Evaluations and Recommendations

After the tabulation has been completed, Engineering makes a recommendation, normally the lowest life cycle cost complying with the specifications, but also taking into account delivery and vendor drawing schedules. If none of the proposals meet the requirements, then the best selection is made based on the technical evaluation, discussions with vendors, and RFQ updates, if necessary.

Only one technical evaluation has been completed at this point. The bids for the dense phase conveying system have been evaluated and a recommendation made; however, a decision has not been made.

It is anticipated that several of the vendors for the mechanical equipment will be selected during the coming quarter.

3.4 Front End Engineering - Liquid SO_2 Plant

3.4.1 Process

Calabrian Corporation, located in Port Neches, TX, has developed and operates a liquid SO_2 facility using the burn in oxygen technology. A description of this process was given in Quarterly Technical Progress Report #15. The Calabrian facility was visited during the past quarter. The purpose of the visit was to gain general knowledge of the process and to acquire information in support of the environmental information volume. Environmental aspects are briefly addressed in Section 3.2. The process related findings are discussed here.

The liquid SO_2 facility at Calabrian was built in 1987 as a pilot plant. It is now operated as a commercial facility with a capacity of 9000 tons per year. Experience from the existing facility will be used to modify the process design for the current project. The current method for removing vaporized sulfur from the SO_2 stream is first a primary condenser where the gas temperature is decreased from about 900°F to 280°F followed by a quench tower and filter pot. The quench tower uses liquid SO_2 from the process to further cool the gas stream and the sulfur is collected in a fiber type filter.

The proposed system will use the same primary condenser, but will be followed by secondary condensers that rely on mechanical forces to remove entrained sulfur vapor. There will be two secondary condensers that operate in parallel. While one condenser is removing sulfur, the other is being regenerated by low pressure steam which melts the sulfur plated out on the condenser surfaces. The melted sulfur will drain into the sulfur storage tank.

The second significant change from the existing plant is an increase in the system operating pressure. The current system operates at 35 psig and therefore requires a chiller system to condense the SO_2. The proposed system will operate at 85 psig and therefore, will require only cooling water to condense the SO_2.

In addition to the above process changes, the oxygen sparger tube will be made of a Haynes alloy, HR-160. This material has proven to have the longest life in the high temperature sulfur environment. The HR-160 sparger tube currently being used in the Calabrian facility has lasted for over 7 months. Previous materials had to be replaced at least every three months.

3.4.2 Mechanical

3.4.2.1 Site Plan

The liquid SO_2 production facility to be constructed at Olin Corporations Charleston, TN plant consists of the liquid SO_2 plant, the air separation plant, a tail gas scrubber and storage tanks for sulfur and liquid SO_2. Relative to Olin's existing facilities the SO_2 production facility will be located in an open area to the east of the switchyard. The storage tanks will be located east of the cooling towers. Figure 3-9 is a drawing of the Olin site plan.

While there appears to be ample room for locating the plant in this area there are some restrictions. Some ground in this area is at an elevation below the 100-year flood plain. Construction in the flood plain would create a time delay and complications in obtaining NEPA compliance and will be avoided. There is a gas line that runs through this area and it is desirable to avoid moving this line. The prevailing wind covers the area east of the cooling towers with a mist the majority of the time, therefore it is desirable to not locate equipment in this area.

3.4.2.2 Equipment Specification

The major equipment for this facility includes an air separation plant and a liquid SO_2 plant. A specification was prepared for each of these plants and sent out for bid.

The SO_2 plant specification did not specify a method for producing the SO_2, but rather specified a production rate and an SO_2 purity requirement. The air separation plant specification allowed for an O_2 purity of 90% or greater. This allows both vacuum pressure swing adsorption (VPSA) manufacturers and cryogenic distillation manufacturers to bid. However, the specification did state a preference for higher purity O_2 (>99%) and also the generation of a byproduct N_2 stream. Only cryogenic systems can meet these two requirements.

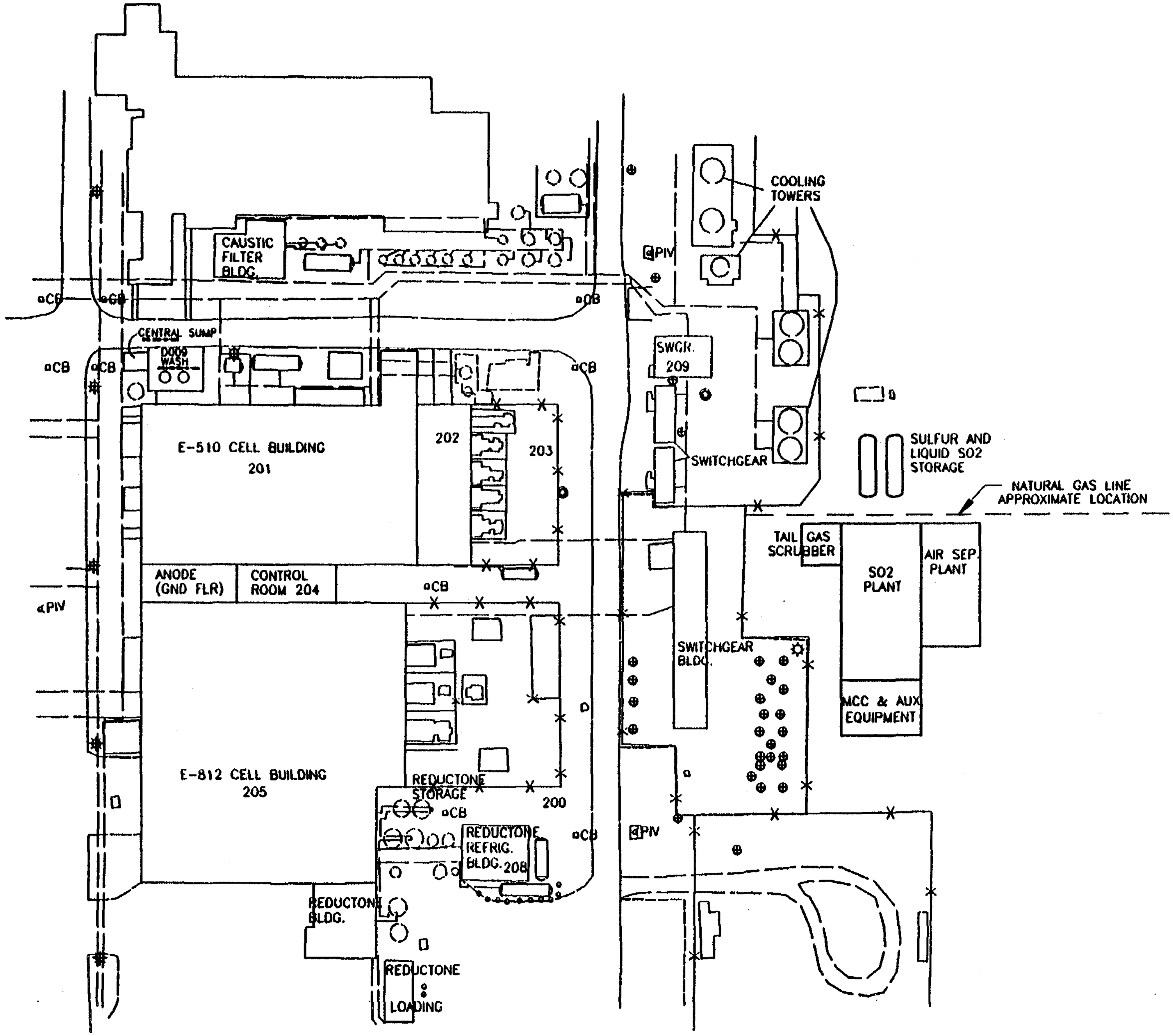


Figure 3-9 Olin Site Plan

In addition to the liquid SO_2 plant and air separation plant, work must be performed on the existing rail yard to accomodate the additional rail traffic generated by this project. The rail work is described later. Future work will include preparation of a specification to get quotes on this rail work.

3.4.3 Civil

3.4.3.1 Site Survey

The proposed site for the liquid SO_2 plant is in an open area however, some of this area is at an elevation that is below the 100-year flood plain. Since any construction in the flood plain invokes a lengthy study to achieve NEPA compliance it is important to avoid placing any part of the liquid SO_2 facility in the flood plain. A detailed topographical survey of the area is required so that the final location of the plant in the proposed area can be determined. Continental Aerial Surveys of Alcoa, TN did a survey of the entire Olin plant. Using the data obtained in their initial fly over they can provide detailed topography of the area in question. The topo lines will be in 1 foot increments. A purchase order was issued to Continental Aerial Surveys on February 24, 1995. It is anticipated that the deliverable drawing and Autocad file will be received about mid-March.

3.4.3.2 Rail Siding

The limitation of having no construction in the flood plain makes it impossible to route a rail siding to the proposed area for the SO_2 plant. SO_2 loading and sulfur unloading will be accomplished by piping these materials to and from the railyard. This will require modifications and additions to the existing yard.

The primary use of the Olin railyard is chlorine loading and chlorine tank car reconditioning. The railyard is also currently used for caustic loading and HCl loading. A new siding will be installed for HCl loading, thereby clearing an area for relocating a chlorine reconditioning station. By relocating a second chlorine reconditioning station an area is cleared for sulfur unloading. Installing a new caustic weigh scale allows the present caustic scale to be used for SO_2 loading. One of the existing chlorine reconditioning stations will be modified for SO_2 car reconditioning. To accommodate the relocation of the one chlorine reconditioning station a track crossover has to be moved.

A work scope for the railyard work will be written and issued to rail contractors in the local area of the Olin plant. This work scope and request for quotation should be issued near the end of March.

3.4.4 Electrical

The primary electricity consumption in the liquid SO_2/air separation plant system is from the air separation plant air compressors. The air compressors represent over 70% of the power consumption in the plants. A preliminary load list was prepared for each plant and is shown in Table 3-6.

Table 3-6 Load List for SO_2 and Air Separation Plants

Air Separation Plant		
Air compressor	1400 hp	1044 kW
Chiller pump	5 hp	4 kW
Regeneration heater	----	40 kW
O_2 product compressor	200 hp	149 kW
Cooling H_2O pump	70 hp	52 kW
Liquid SO_2 Plant		
Sulfur pump	5 hp	4 kW
Liquid SO_2 pump	5 hp	4 kW
boiler feedwater pump	5 hp	4 kW
Scrubber effluent pump	5 hp	4 kW
Electric heaters	---	150 kW
Cooling H_2O pump*	---	---
Total		1455 kW

*Included with the cooling water pump in the air separation plant.

The load list will be updated once formal quotes are received from vendors.

3.4.5 Procurement - RFQ

The SO_2 plant bid package was completed and sent to two qualified vendors for quotation. One quote will be for a burn in air system and the second will be for a burn in oxygen system. A construction subcontract for the burn in oxygen system is being competitively bid among three qualified subcontractors.

The air separation plant bid package was sent to six qualified vendors for quotation. It is expected that both VPSA and cryogenic distillation systems will be quoted. It is also expected that both purchase and lease arrangements will be proposed.

4 PLANS FOR NEXT QUARTER

The Continuation Application (CA) and Funding Increase Request will be prepared and submitted to DOE in April. Included with this CA will be an updated project estimate. Also, the additional contingency items identified in the January 11, 1995 project amendment will be addressed.

The EIV will be completed by NOXSO and a NEPA determination will be made by the DOE. The determination will identify whether a Categorical Exclusion (CX) or Environmental Assessment (EA) is required. After the determination is made, the appropriate NEPA document will be prepared. The objective is to obtain NEPA compliance before the continuation application is submitted to headquarters at the beginning of May.

The PFD for the NOXSO plant will be Issued For Construction (IFC). The HAZOP is also scheduled for completion by the end of the quarter. Following completion of the HAZOP, the P&ID's will be IFC.

Construction of the laboratory-scale, multi-stage, fluid-bed adsorber will be completed. Testing will be conducted to quantify the benefit of adding a third stage to the adsorber and the number of adsorber stages for the commercial plant will be decided.

Contracts for the site and geotechnical survey will be awarded and both will be completed. Based on the geotechnical survey, the preliminary foundation design will be modified.

Equipment vendors will be selected and vendor engineering purchased as required to provided dimensional data and weights for use in preparing a final general arrangement.

The design of the process vessels will be completed. Fixed price bids will be solicited and vendors will be selected. Engineering will be purchased as necessary to obtain the necessary delivery schedule to satisfy the construction schedule.

Electrical equipment specifications will be prepared and RFQ's will be issued.

Preparation of the mechanical, civil/underground/architectural, and electrical/controls work packages will begin.

A topographical survey of the Olin site in the area of the liquid SO_2 facility will be obtained to assure the project is not in the 100-year flood plain. A geotechnical survey will also be performed for use in specifying the foundation requirements. Using this information, the final site location will be selected.

A scope of work for the necessary railroad work at the Olin site will be prepared and bids will be solicited. General work scopes will be written for engineering and construction activities for use in qualifying potential subcontractors.

Bids on the air separation plant and liquid SO_2 plant for the liquid SO_2 production facility will be received. Commercial and technical evaluations of the bids will be made and vendors will be selected.